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# Strain Gauge Design for Compliant Materials

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## 1 Introduction

Strain gauges are the most common used strain measurements device and are in general considered very reliable. A strain gauge will measure the applied strain in a substrate material through an electrical resistance change measured along an approximately $5\,\mu\mathrm{m}$ thick and $30\,\mu\mathrm{m}$ wide conductive wire made of a $180\,\mathrm{GPa}$ stiff constantan alloy printed as a measurement grid on a $45\,\mu\mathrm{m}$ thick backing polymeric film. The electrical resistance change is related to a strain value through a gauge factor found calibrating the strain gauge on a $200\ \mathrm{GPa}$ stiff reference material. The gauge factor is provided by the strain gauge manufacture together with the specific strain gauge batch. Even for moderate stiff materials such as thermosetting polymers with or without fiber reinforcements with $E \in [3;35]\,\mathrm{GPa}$, strain gauges are often considered as a reliable strain measurement. Nevertheless, even for thick test samples, conventional strain gauges has found to measure 1-9% lower strains compared with other strain measurements methods [1]. Inspired by those experimental observations, an extensive finite element study has been performed modelling the actual 3-dimensional structure of the strain gauge mounted on a moderate stiff substrate. The finite element study support the experimental observations as shown in [1]. Based on the observations, a new strain gauge design has been suggested [2], a strain gauge design which is actually just a small modification of a conventional grid pattern. Based on the new strain gauge design, it is possible to reduce the measurement error with a fixed gauge factor to below 1% for materials covering the stiffness range $E \in [3;200]\,\mathrm{GPa}$.

## 2 Verification of the cause for the strain gauge measurement error

During material testing, precise strain measurements are essential for precise experimental determination of stiffness parameters such as the Young's Modulus, Poisson's ratio and the shear modulus. Following the test standard [3], the Young's modulus should be determined in the strain range $\varepsilon \in [0.5;0.25]\%$. Fig. 1a shows the strain field around the measuring grid of a conventional 3 mm strain gauge mounted on a 3GPa stiff thick substrate loaded to an overall strain level on 0.25%. It can be seen that even though the measuring grid is only $5\,\mu\mathrm{m}$ thick, the part of the grid exposed to significant smaller strains is rather large. A strain inhomogeneity caused by the significant higher stiffness of the measuring grid. By introducing a stiffer part at the end of the measuring grid which do not taken part of the strain measuring grid, see Fig. 1b, it is possible to move the strain inhomogeneity outside the measuring grid. A solution described in the patent application [2].

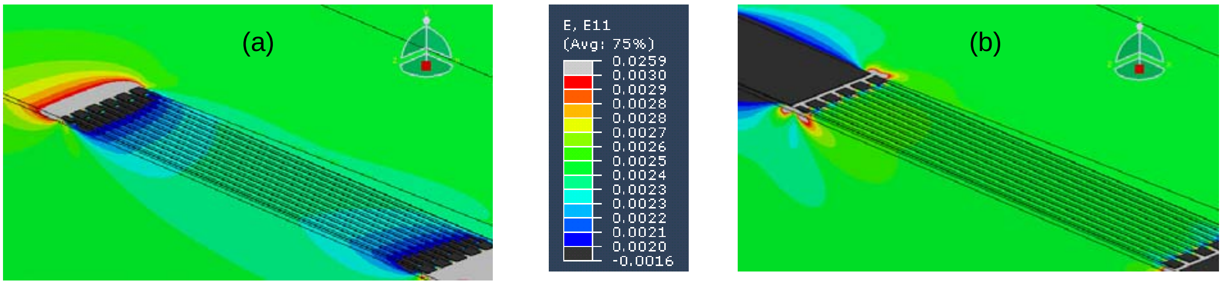


Fig. 1
The axial strain variation around the measuring grid of a conventional (a) and an enhanced (b) strain gauge grid design, respectively, shown at an overall strain level at 0.25% strain.

## 3 Numerical validation of the measurement error

Based on the numerical finite element model presented in Fig. 1, the measurement error for the conventional and the improved strain gauge design can now be predicted. Fig. 2 show such a comparison for material stiffness's in the range of $E \in [1;200]\,\mathrm{GPa}$. The strain gauges has numerical been calibrated using a $E = 200\,\mathrm{GPa}$ stiff material similar to the calibration performed by a strain gauge manufacturer. It can be seen that the edge effect for the conventional strain gauge shown in Fig. 1 results in significant large measurement error of the E-modulus for materials with stiffness below 35GPa. Predictions which has been experimental validated [1]. On the other hand, by a simple modification of the grid design outside the measurement grid (adding a reinforced region), it is possible to retain the measurement error inside $\pm 1\%$ for the full stiffness range $E \in [3;200]\,\mathrm{GPa}$. A stiffness range which includes structural important materials such as thermosetting polymers with or without fiber reinforcements.

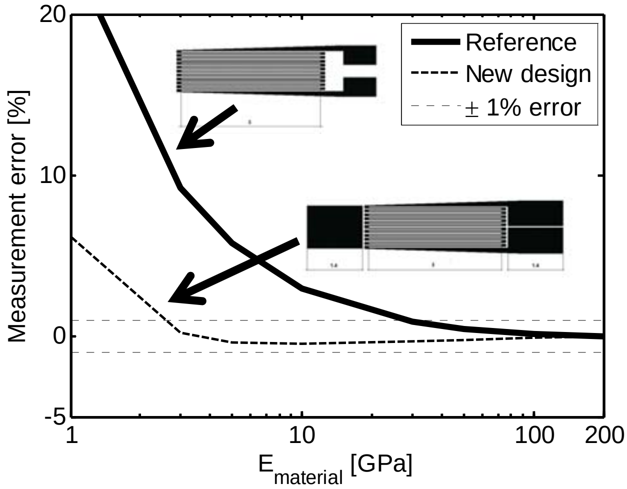


Fig. 2
Predicted strain gauge measurement error as a function of the stiffness of the test material for a conventional and an enhanced strain gauge with 3mm long measurement grid.

## 4 Conclusion

Using the finite element method, it has been demonstrated how the source for an experimental observed measurement error can be identified. Based on this identification, a significant improved grid design has been proposed and validated numerically. A grid design which is judge only to cause an insignificant increase in the manufacture cost. On the other hand, the improved strain gauge design has been predicted to significantly lower the resulting measurement error using the strain gauge on materials with a moderate Young modulus in the range of $E \in [3;200]\,\mathrm{GPa}$.

## 5 References

[1] S. Zike and L. Mikkelsen, “Correction of Gauge Factor for Strain Gauges Used in Polymer Composite Testing,” *Exp. Mech.*, pp. 393–403, Oct. 2014.

[2] L. P. Mikkelsen and S. Zike, “A strain gauge,” Patent Application: EP14180022.72014.

[3] ISO-527-1, “527-1: Plastics—Determination of tensile properties—Part 1: General principles,” *Reference EN ISO*. 1997.